SSL-LED Load modelling through measurement

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Background load-system interaction

As with other light source technologies, such as fluorescent and high intensity discharge, lighting systems using LEDs can be thought of as having individual LED sources, an AC/DC converter, often called a driver, and a luminaire. An LED driver performs a function similar to a ballast for discharge lamps. It controls the current flowing through the LED. Most LED drivers are designed to provide current to a specific device or array. An SSL-LED lighting system containing AC/DC converters represents a nonlinear voltage-dependent load.

SSL LED load-system interaction can be conveniently analysed by decomposing the power system into a feedback system such as shown in Figure 1. The figure shows a real power disturbance ΔP but in general the ideas remain valid whether the disturbance is real or reactive power or a combination of both. The SSL-LED load provides a feedback path, and so has the potential to alter the overall system behaviour.

If it is considered a sinusoidal variation in bus power ΔP then a variation in the bus voltage ΔV will result. The magnitude of that variation, and its phase relative to ΔP, will depend on the transfer function of the power system.

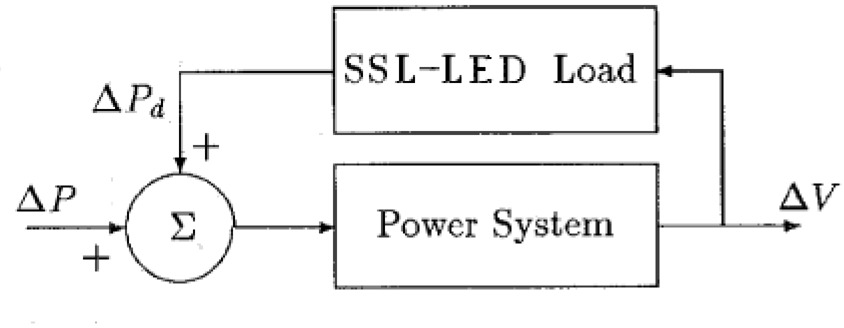


Figure 1: SSL-LED load - power system interaction.

But ΔV will induce, through the load, some variation ΔP_d. The magnitude of this ΔP_d, and its phase relative to ΔV are given by the transfer function of the load.

The view of load-system interaction given by Figure 1 is useful for analysing the effects due to a single load.

Load Model

Load modelling trough recommendation of the IEEE working group and utilities in utilizing the voltage-dependent load model for composite load representation. Utilities normally perform field tests, or in some cases perform regression analysis to establish system load models to be used for power-flow and stability studies, these models are in the form of:

$$P_L = P_{L0} V_t^{n_p} \quad (7)$$

$$Q_L = Q_{L0} V_t^{n_p}$$

Where:

P_L and Q_L are the load active and reactive power.

V_t is the load bus voltage.

np and nq are the load parameters.

P_{L0}, Q_{L0}, and V_{t0} are the nominal value of load active power, load reactive power, and bus voltage prior to a disturbance.

The load representation given in equation (7) makes possible the modelling of all typical voltage-dependent load models by selecting appropriate values of load parameters (n_p and n_q). With load parameters equal 0, 1, or 2, the load model represents constant power, constant current, or constant impedance characteristics. The values of n_p and n_q depend on the nature of the load and can vary between 0 to 3.0 for n_p and 0 to 4.0 for n_q. The measurement of typical values of n_p and n_q of various kinds of typical power system composite loads are reported in [16]. These measurement values are required for control parameter adaptation.

The Influence of the Non-linear Load (AC to DC Converter) on the Low Voltage System Operation

A switch-mode AC/DC converter is the electronic circuit that is used as a dc-current source for the LEDs clusters emitters. The configuration used is a buck converter, whose basic structure is shown in **Figure 1**. When the switch is on, the input voltage from a rectifier bridge charges the output capacitor, which discharges itself through the load when the switch is off.

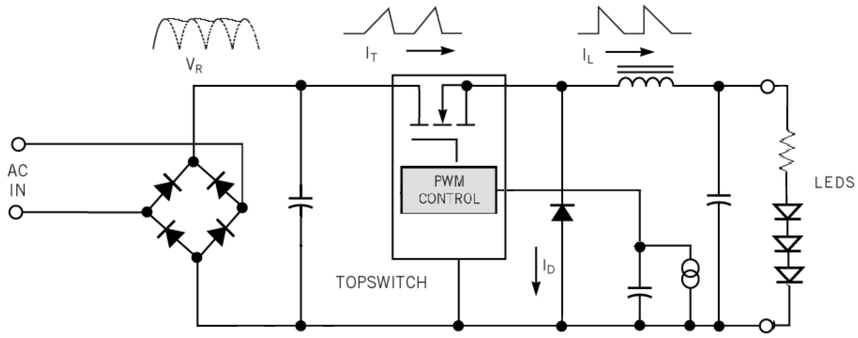
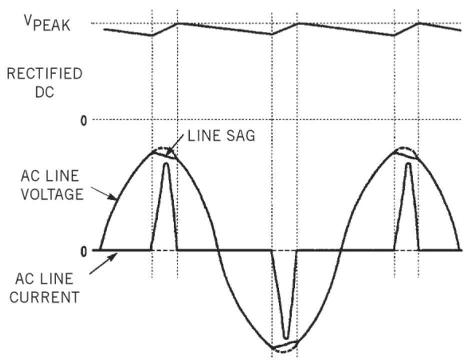


Fig. 1. Basic structure of the buck converter.

Left uncompensated, the bridge rectifier/capacitor front-end in linear and switch-mode power supplies presents a highly nonlinear load to the ac line as the capacitor charges only toward peaks of the sinusoid, creating a pulse-current waveform **(Figure 1**a). This pulse current typically contains harmonics at small but significant energy levels beyond 1 KHz **(Figure 1**b). Multiplied by internal PWM circuitry, the effect is to create harmonic pollution and reduce supply-network capacity. Switch-mode converters generate a complex frequency component that a couple back into the supply line and creates local disturbances of varying severity.



Conversely, the requirement to supply substantial amounts of reactive power decreases network capacity as the current waveform moves further out of step with voltage.

There are safety implications, too; all power derives from three-phase supplies, in which the neutral current should ideally be zero. But, in severe cases, harmonic currents can create phase imbalances that impress neutral-line currents as high as

1.7 times phase current, causing components such as transformers, phase-correction capacitors, motor windings, and neutral-line conductors to overheat.

In general, lower order harmonics have the largest amplitude, with distortions that appear uniformly on both half-cycles creating only odd-order harmonics, such as the ubiquitous "triplen" series (third, sixth, ninth, and so on). Differences between the positive and negative half-cycles or a dc component in the ac waveform caused by rectification create even-order harmonics. In general, emissions from nonlinear loads tend to add at the dominant low-order end up to the fifth or seventh harmonic, and higher order harmonics can end toward canceling themselves out; odd triplens (third, ninth, 15^{th}, and so on) tend to add, however.

Function Control

There are four (4) important factors associated with extremely non-linear loads such as switch-mode power supplies (SMPS). These factors are:

- Crest Factor
- Repetitive & Non-Repetitive peak load currents
- Harmonic Voltage Distortion
- Inverter Technology

CREST FACTOR

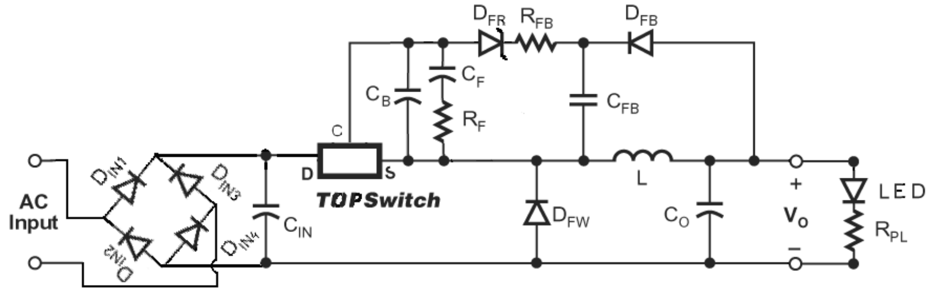
Literature make reference to a ratio often called "Crest Factor" which is simply the ratio of the peak current value divided by the root-mean-square (RMS) value.

Suppose we construct a hypothetical distributed control system that will require (20) twenty control modules, with each control module using one switch-mode power supply. Let us further suppose that in our hypothetical system, the power supply is a 200W model as shown in Table "B". (Table "B" is a typical listing of the SMPS input characteristics).

Table B

Input voltage	Input Amps Steady	Input VA	Peak input	Crest factor	Inrush Input	Input power	3^{rd} harmonic	5^{th} harmonic

	stage		Amps		Amps	factor		
230V	3.6A	432VA	12.2A	3.4	24A	0.60	80%	52%
230V	0.27A	5.8VA	1.2A	4.4	7A	0.60	68%	40%



This supply can produce 200 watts of DC output power, has a 240 V, 50 Hz input, and is designed to maintain its DC output voltage for 10 milliseconds with a total loss of AC input. This power hold-up time is supplied from an internal 470 UF or VF electrolytic capacitor (**Figure 2** component "C") Since our DCS system will use twenty (20) of these supplies in its overall control scheme, one might be tempted to multiply the 432 VA input demand times 20 and add "fudge" factors because of the large crest factor (Table "B", column 5B).

The assumption, of course, is that the crest factor of the switch-mode supply is a constant value. Table "C" summarized actual values taken on a 10 kVA ferroresonant inverter with a simulated switch-mode load. The load of 8.43 kVA is very close to our hypothetical load of twenty (20) 200W power supplies. In Table "C", notice that the load crest factor has decreased from 3.4 to 2.3. This reduction in crest factor is a result of a change in the source to load impedance ration (Zs/Zl, see figure 3). An example will clarify the concept:

Suppose that when the original performance data in Table "B" was measured, a 3 kVA transformer with a 5% impedance was used to provide power to a single 200 watt supply.

Table C

Nr of SMPS	Input	Input Amps	Input	Peak input	Crest	Inrush Input	Input power	3^{rd}	5^{th}

loads	voltage	Steady stage	VA	Amps	factor	Amps	factor	harmonic	harmonic
20	124V	68A	8.4kVA	156A	2.3	460A estimated	0.74	72%	38%

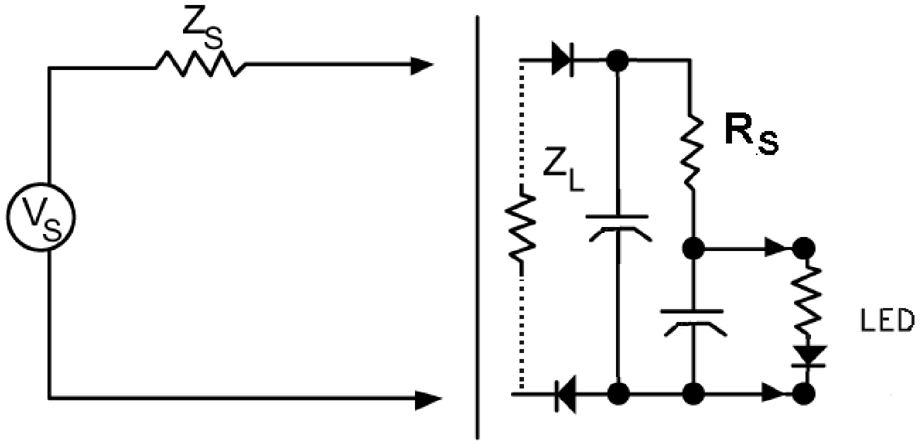
The source-load impedance ratio in this case would be:

$Z_S / Z_K = 0.24/0.33 = 1/138$

Where $Z = E^2 VA$

If we were to add (5) five more 200W supplies for a total of 6 units, the new ratio would be:

$Z_S / Z_L = 0.24/5.5 = 1/23$

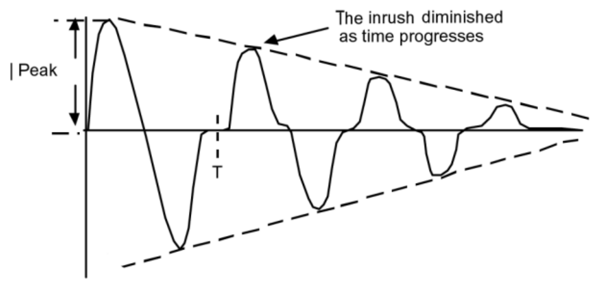


Published power supply data rarely takes this effect into account and thus actual crest factors will be lower. The reduction in crest factor is a predictable and repeatable result whenever switch-mode power supplies are used with power sources that have inductive reactance in series with the switch-mode power supply. In Table “C”, the inverter’s output reactance reduced the load crest factor. The reduction in crest factor is accomplished by changing the shape of the switch mode’s input current waveform to a wider shape with less amplitude. The area under the current curve tends to remain constant, but the harmonics, particularly the 3rd and 5th, are attenuated. The peak current has been reduced

from a predicted value of 12.2 x 20 =224 A (Table"B" column 4B) to an actual value of 156A. (Table "C" column 4C).

Peak current effects

This topology is commonly called an "on-line" system because the inverter normally supplies the critical load. Between the inverter and the critical load is an electronic switch (static) that will transfer the critical load to a fail-over source (static bypass), should the load current demand exceed the inverters rated capacity (or should the inverter fail). If the static switch is designed for sinusoidal current with a crest factor of 1.414, then a non-sinusoidal current with a crest factor of 2.4 will cause premature load switching to bypass. Static switch transfer sensing for over current is best accomplished with true RMS values rather than peak current values. For example, if the 10kVA system (Table "C" data) had used a sinusoidal, peak sensing current design the connected loads peak current of 156A (column 4C) would have been 11% over its static switch transfer point, assuming a 120% overload capacity. True RMS sensing rather than peak sensing is a very important feature in a well-designed system to prevent premature static switch operation.



The cold start inrush current (Table "B & C", Columns 6B & 6C) is also important when selecting an inverter system. Switch-mode power supplies are sensitive to the peak voltage of their input supply. Figure 5 shows the characteristics wave shape of the input current during the first several cycles of a cold start.

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